11 The arts

'Art is what you can get away with.'
Andy Warhol, 1928–87

'Life imitates art more than art imitates life.'
Oscar Wilde, 1854–1900

'Art is meant to disturb, science reassures.'
Georges Braque, 1882–1963

'The essential function of art is moral.'
D. H. Lawrence, 1885–1930

'Art is not a copy of the real world; one of the damn things is quite enough.'
Virginia Woolf, 1882–1941

'Lying, the telling of beautiful untrue things, is the proper aim of art.'
Oscar Wilde, 1854–1900

'An artist is always out of step with the time. He has to be.'
Orson Welles, 1915–85

'Art is a human activity, whose purpose is the transmission of the highest and best feelings to which men have attained.'
Leo Tolstoy, 1828–1910

'God is really only another artist. He invented the giraffe, the elephant and the cat. He has no real style. He just goes on trying other things.'
Pablo Picasso, 1881–1973

'The art of seeing nature is a thing almost as much to be acquired as the art of reading the Egyptian hieroglyphs.'
John Constable, 1776–1837

'Art is a lie that makes us realize the truth – at least the truth that is given us to understand.'
Pablo Picasso, 1881–1973

'[In poetry] new things are made familiar and familiar things are made new.'
Ben Jonson, 1572–1637

'The only end of writing is to enable the readers better to enjoy life or better to endure it.'
Samuel Johnson, 1709–84

'Good writers define reality; bad ones merely restate it.'
Edward Albee, 1928–

'The great artist is a simplifier.'
Henri Frédéric Amiel, 1821–81

means that it is always possible that we have overlooked a factor that later turns out to be relevant. For example, when you do an experiment in chemistry, you do not normally count how many people are in the room. However, this will affect the temperature of the room, and in a sensitive experiment that might affect the speed of the chemical reaction.

Expectations

Another problem with observation is that *our expectations can influence what we see.* When the planet Mercury was found to be deviating from the orbit predicted by Newton's laws, some nineteenth-century astronomers suggested that the anomaly was caused by an undiscovered planet called Vulcan. So confident were they in their belief that several astronomers then claimed that they had observed Vulcan. But it turned out that Vulcan does not exist. The correct explanation for the deviation of Mercury had to wait for Einstein's theory of relativity.

Expert seeing

The use of *scientific equipment* such as microscopes and telescopes to make observations further complicates things. We may laugh when we hear that some of Galileo's contemporaries refused to look through his telescope preferring to rely on the authority of the Church rather than the evidence of their senses. But it is worth pointing out that the telescope Galileo used to discover the phases of Venus and the moons of Jupiter was a fairly crude instrument. Some of Galileo's drawings of the moon are quite inaccurate and include some craters and mountains that do not in fact exist. From your own experience in the science lab, you are probably aware that it takes quite a lot of practice to learn how to see through a microscope.

The observer effect

A final problem with observation is that *the act of observation can sometimes affect what we observe.* To take a simple example, imagine that you want to know exactly how hot a cup of tea is. You put a thermometer in the tea and read off the temperature. The problem is that, instead of measuring the temperature of the tea, you are now measuring the temperature of the tea-with-the-thermometer-in-it. The very act of putting the thermometer in the tea has changed its temperature. Of course, for most practical purposes this does not make a significant difference. If you are in bed with a fever and the doctor comes and tells you that you have a temperature of 102 °F, it would be pedantic to point out that she has in fact taken the temperature of you *plus* the thermometer. However, the effect of the observer on the observed plays an important role in a branch of physics known as quantum physics. We shall also have more to say about the observer effect when we discuss the human sciences in the next chapter.

While our discussion has focused on the fallibility of perception, it is important not to exaggerate the problem. The great strength of science is that it is a communal and self-correcting enterprise. Sooner or later the errors of one individual are likely to be corrected by someone else.

'An uneducated child and a trained astronomer, both relying on the naked eye and twenty-twenty vision, will literally see a different sky.' What do you understand by this quotation?

Testing hypotheses

Testing hypotheses is also less straightforward than the naive account of the scientific method implies. Among the complications are: confirmation bias, background assumptions and the fact that many different hypotheses are consistent with a given set of data.

Confirmation bias

Confirmation bias refers to the fact that people tend to look for evidence that confirms their beliefs and overlook evidence that goes against them. If, for example, you believe that Virgos are particularly shy individuals, you will notice every time you come across a shy Virgo. But if you only observe confirming instances of your hypothesis this does not show that it is true. You also need to look for evidence that might falsify it.

In the above example, as well as looking at Virgos who are shy, what else might you look at that could falsify your hypothesis?

The two other key things you should look out for are: (a) Virgos who are not shy; and (b) people of other star signs who are also shy. When all the evidence is in, it may turn out that, despite your initial belief, there is no relationship between a person's star sign and whether or not they are shy.

A good scientist will be aware of the danger of confirmation bias and actively seek to combat it. In one of his notebooks Charles Darwin (1809–82) stated that 'I followed a golden rule, namely that whenever a new observation or thought came across me, which was opposed to my general results, I make a memorandum of it without fail and at once; for I had found by experience that such facts and thoughts were far more apt to escape from the memory than favourable ones.' This is a tribute to Darwin's intellectual integrity.

One common form of confirmation bias is for a scientist to dismiss results they don't expect as 'experimental error'. Imagine, for example, that you do an experiment and get the following results. You would probably be tempted to ignore observation X_4.

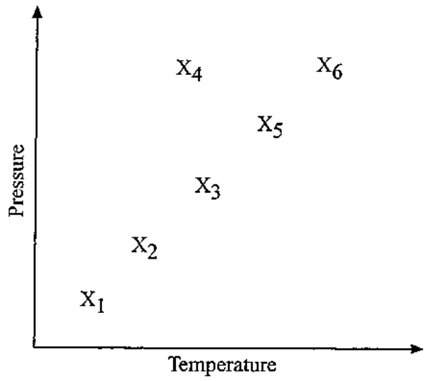


Figure 8.3 Pressure–temperature graph

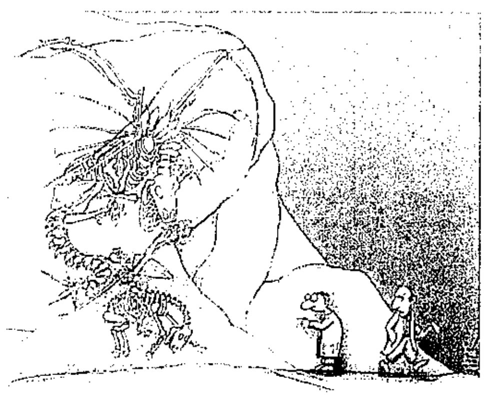
> To what extent do you think you would be justified in dismissing observation X_4 in this example as experimental error?

In the above case, it might seem reasonable to assume that X_4 is a result of human error, but it would be wise to take more observations to be on the safe side. In practice, however, it is difficult to say where 'trimming' one's results to exclude experimental error ends and 'cooking the books' begins. Scientists naturally want to show their results in the best possible light, and they often have strong expectations about the way an experiment should turn out. When the notebooks of one famous physicist were examined, the following comments were found alongside his experimental observations:

'Very low. Something wrong.'
'This is almost exactly *right* and the best one I have ever had!!!'
'Agreement poor.'

To take another example, Gregor Mendel's (1822–84) work on the hereditary traits of peas laid the foundations for modern genetics. But according to some modern geneticists, his results are just too good to be believable, and he has been accused of only reporting results that favoured his case. The following is an amusing account of Mendel's method:

> IN THE BEGINNING, there was Mendel, thinking his lonely thoughts alone. And he said: 'Let there be peas,' and there were peas, and it was good. And he put the peas in the garden, saying unto them, 'Increase and multiply, segregate and assort yourselves independently,' and they did, and it was good. And now it came to pass that when Mendel gathered up his peas, he divided them into round and wrinkled and called the round dominant and the wrinkled recessive, and it was good. But now Mendel saw that there were 450 round peas and 102 wrinkled ones; this was not good. For the law stateth that there should be only three round for every wrinkled. And Mendel said unto himself, 'Gott in Himmel, an enemy has done this; he has sown bad peas in my garden under the cover of night.' And Mendel smote the table in righteous wrath, saying, 'Depart from me, you cursed and evil peas, into the outer darkness where Thou shalt be devoured by the rats and mice,' and lo, it was done, and there remained 300 round peas and 100 wrinkled peas, and it was good. It was very, very good. And Mendel published.



"No, ignore that one Davies. It's unscientific."

Figure 8.4

Background assumptions

Whenever we test a hypothesis, we make various background assumptions, any one of which could turn out to be false. For example, at the time of Copernicus, it was generally agreed that the fixed stars are relatively close to the earth. Given this, it follows that if the earth is orbiting the sun the position of nearby stars relative to more distant stars ought to change as the earth moves round the sun. Such a change of relative position is known as a *parallax*. (An analogy may help you to get the point here. Hold a pencil out in front of you so that it exactly covers a distant object, such as a tree. If you now close each of your eyes in turn, the position of the pencil relative to the tree will appear to change. In a similar way, the relative position of the stars should change if the earth is moving.) The problem was that no one was able to observe the required parallax; and neither Copernicus nor Galileo had an answer to this criticism. Finally it turned out that the assumption that the fixed stars are relatively close to the earth was wrong, and in the nineteenth century the stellar parallax was finally observed.

Many different hypotheses are consistent with a given set of data

Since it is possible to come up with many different hypotheses that are consistent with a given set of observations, it is in practice impossible to *prove* that any particular hypothesis is true. For example, in our discussion of astronomy above, I said that Galileo saw that the relative size of Venus changes as predicted by Copernicus' heliocentric theory. While this observation is inconsistent with Ptolemy's model, it is in fact consistent with another model according to which the sun orbits the earth and the other planets orbit the sun.

In fact, there are an endless number of different hypotheses consistent with a given set of observations. This can be easily shown by considering the graphs below. Imagine you are investigating the relationship between the temperature and pressure of a gas. You make some observations, X_1, X_2 and X_3. On the basis of your observations, you formulate a hypothesis H1, and make a prediction P. Your prediction is confirmed. Does this conclusively confirm hypothesis H1? No! For your observations are also consistent with another hypothesis H2.

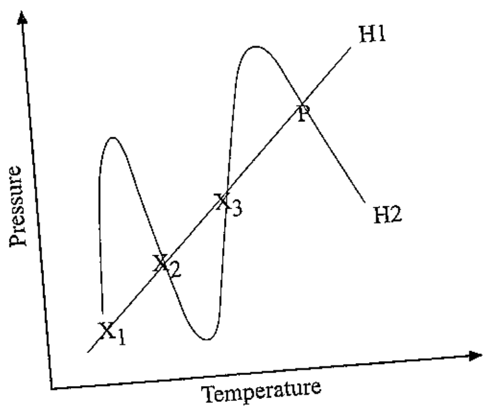


Figure 8.5 Temperature–pressure graph showing hypotheses H1 and H2

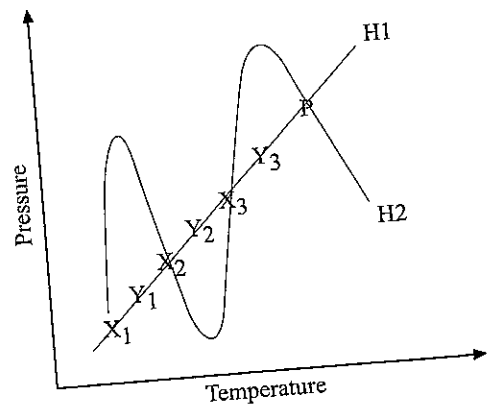


Figure 8.6 Temperature–pressure graph, with extra observations

To decide between hypotheses H1 and H2 you might make some further observations, Y_1,Y_2 and Y_3 as in Figure 8.6. These new observations would seem to confirm H1 and eliminate H2.

But once again H1 is not conclusively confirmed. For we might now make another hypothesis H3 which is also consistent with our observations (Figure 8.7). Further observations might eliminate H3 and confirm H1, but you could then make another hypothesis H4 and so on. Extrapolating from this, you can see that, no matter how many observations you make confirming H1, there will always be other hypotheses that are also consistent with the data.

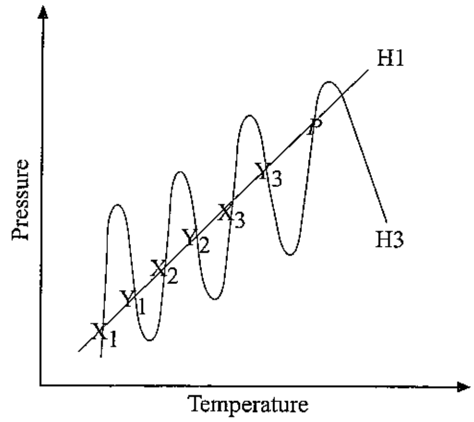


Figure 8.7 Temperature–pressure graph with new hypothesis H3

The principle of simplicity

Having said that, hypotheses such as H3 do seem absurd, and it is hard to avoid thinking that H1 is the more natural hypothesis. In fact, scientists usually appeal to a **principle of simplicity** which says that given two competing theories which make exactly the same predictions the simpler theory is to be preferred. This justifies our preference for H1 over H2 or H3. However, if you asked a scientist to justify their belief in the principle of simplicity, they would probably shrug their shoulders and say that's just what they believe. The principle reflects a deep belief in the orderliness and comprehensibility of nature, but no further justification can be given for it. Since simplicity is also related to concepts such as 'beauty' and 'elegance', we can say that in practice aesthetic considerations are likely to play a role in a scientist's choice of hypothesis.

But we must be careful. For our aesthetic prejudices can sometimes lead us astray. Copernicus was convinced that the planets must orbit the sun in circles because he thought that a circle is a perfect figure. However, it turned out that planetary orbits are elliptical rather than circular. The moral of the tale is that nature's aesthetic may not be the same as our own, and beautiful theories are sometimes slain by ugly facts!

The problem of induction

A final problem with the naive picture of the scientific method concerns induction. As we saw in Chapter 5, inductive reasoning goes from the particular to the general, and it plays a central role in the way that scientists think. Take, for example, our belief that all metals expand when heated. How did we come by this belief? Not by reason, or intuition, or divine revelation, but by observation. As far as we know, every time a piece of metal has been heated, it has expanded, and there are no recorded cases of metals not expanding when heated. So it seems reasonable to conclude that this is a law of nature. What's the problem?

Although it is unlikely to keep you awake at night, the problem is that when we reason inductively we are moving from the observed to the unobserved. For example, when we reason that since metal A and metal B and metal C etc. expand when heated, then *all* metals expand when heated, we are making a generalisation from things we have observed to things we have not observed.

Practical problems

At a practical level, the problem of induction raises the question of how many observations we should make before we are entitled to make a generalisation. We saw in Chapter 6 that we have a tendency to jump to conclusions on the basis of insufficient evidence, and we looked at various criteria for distinguishing reasonable generalisations from unreasonable ones. But there is no hard and fast rule about how many observations you should make before you are entitled to generalise. All we can say is the more observations you make that support your hypothesis the more confident you will feel about it.

The trouble is that even well-confirmed generalisations sometimes let us down. Up until the eighteenth century, it was commonly believed by Europeans that all swans are white. There were innumerable confirming instances of this belief and no disconfirming instances. Then some black swans were discovered in Australia. More dramatically, for two and a half centuries experiment after experiment seemed to confirm the truth of Newtonian physics. Nevertheless, Einstein showed that there is a deep sense in which Newton's laws are not the best description of physical reality. What this appears to show is that even very well-confirmed hypotheses can sometimes turn out to be wrong.

When you start to think about it, our confidence in scientific knowledge is quite breathtaking. On the basis of a few observations that we have made on planet Earth, we claim to have discovered laws of physics that apply to *all* times and *all* places – billions of years ago and billions of light-years away. Yet we have observed only a minute fraction of the universe. (As we mentioned in Chapter 1, astronomers estimate that there are ten times more stars in the night sky than grains of sand in the world's deserts and beaches!)

Given the above, you might argue that scientists should show greater humility and make less ambitious claims. For example, instead of saying 'all metals expand when heated', perhaps we should restrict ourselves to the more modest assertion that 'all *observed* metals expand when heated'. This may show admirable humility, but the fact is that deep down most physicists believe that they really are discovering the fundamental laws in accordance with which the universe operates.

Theoretical problems

The problem of induction bites not only at the practical level, but also at the theoretical level. For science is supposed to be an *empirical* discipline which makes no claims beyond what has been observed. Indeed, the claim that it is grounded in observation is supposed to be what distinguishes genuine science from pseudo-science. So we seem to be faced with a dilemma. On the one hand, we could take the alleged empiricism of science seriously, and refuse to make any claims that go

beyond what has actually been observed. There would, however, be a very high price to pay for this. For it would mean that we would have to abandon any talk of discovering laws of nature that apply in all times and all places. On the other hand, we could defend the right of scientists to reason from the particular to the general, and abandon the claim that science is a strictly empirical discipline. Again, this seems to be a high price to pay. Another approach is to simply not worry about the problem too much and just get on with the business of doing science!

The scientific method: summary of problems	
Observation	1. Selectivity 2. Expectations 3. Expert seeing 4. The observer effect
Hypothesis	5. Confirmation bias 6. Background assumptions 7. Under-determination
Law	8. Problem of induction

Write short paragraphs explaining each of the above problems in your own words.

Falsification

One person who took the problem of induction seriously and tried to resolve the dilemma was a philosopher called Karl Popper (1902–94). Popper's interest in the problem grew out of his concern to distinguish genuine science, such as Einstein's theory of relativity, from what he saw as pseudo-science, such as Marxism and psychoanalysis.

As a young man, Popper had been impressed by the ability of theories put forward by people such as Karl Marx (1818–83), Sigmund Freud (1856–1939) and Alfred Adler (1870–1937) to explain *everything*. Adler, for example, believed that human beings are dominated by feelings of inferiority. 'To be human', he said, 'means to feel inferior.' He then used this insight to explain more or less the entire range of human behaviour. As impressive as this seems, Popper came to the conclusion that what looked like a strength of the theory – its ability to explain everything – was in fact a weakness.

Imagine, for example, that a man is walking along the bank of a fast-flowing river when he sees a child fall in. He has two choices: either he jumps in and tries to rescue the child or he does not. Suppose that he jumps in and tries to rescue the child. 'Ah', says Adler, 'this is exactly what my theory predicted. The man was clearly trying to overcome his feeling of inferiority by demonstrating his bravery.' Now suppose that the man does not jump in to the river. 'Just as I thought', says Adler. 'This man is clearly suffering from an inferiority complex which he is unable to overcome.'

The above may be a caricature of Adler's beliefs, but the point I want to emphasise is that from a scientific point of view *a theory that explains everything explains nothing*. According to Popper, a genuinely scientific theory differs from the one considered above in that it puts itself at risk. For example, Einstein's general theory of relativity led to certain predictions being made which were famously tested and confirmed in 1919. Had the relevant observations not confirmed Einstein's theory, scientists would have rejected it.

Figure 8.8

Conjectures and refutations

The scientific method advocated by Popper is based on **conjectures and refutations**. A conjecture is basically an imaginative hypothesis and, in his discussion of conjectures, Popper emphasises the fact that there is no mechanical way of coming up with good hypotheses on the basis of the observational data. What is frequently required is a leap of imagination that enables you to look at the data in a different way. This is essentially what Copernicus did when he first put forward the idea that the earth goes round the sun rather than vice versa. As we saw when discussing intuition in Chapter 6, scientists often have their best ideas in a flash of intuition. For example, Newton is said to have come up with the idea of universal gravity when he saw an apple fall from a tree, and Mendeleyev's idea for the periodic table came to him in a dream. However, you are only likely to have such intuitions if you have the right background knowledge and have put in the necessary work. When Newton was asked how he had discovered the law of gravity, he replied 'By thinking on it continually'. And Mendeleyev made a set of cards with the names of the elements written on them, and played around with them endlessly before he finally made his great breakthrough.

The most important thing about genuinely *scientific* conjectures is that they are *testable*. This brings us to the concept of 'refutations' and Popper's attempt to solve the problem of induction. In thinking about this problem, Popper was struck by the asymmetry between confirmation and falsification. Consider again our standard example, 'All metals expand when heated.' We cannot be sure that the law is true no matter how many confirming observations we have made; for it is always possible that the next metal we test will *not* expand when heated. But we only need to find one metal which does *not* expand when heated to be sure that it is *false* that all metals expand when heated. In other words, while confirmation is tentative and

cannot prove that a law is true, refutation is decisive: we need only one counter-example to prove that a law is false.

The conclusion Popper drew from this is that scientists should not waste their time trying to prove that their hypotheses are true; for the problem of induction shows that this is impossible. Rather, they should spend their time trying to prove that their hypotheses are *false*. Despite its strangeness, Popper's ingenious approach is in many ways attractive. He believed that a properly scientific approach to a subject should explore the shortcomings of currently accepted theories. What he disliked above all was any form of scientific dogmatism which blindly accepted the prevailing orthodoxy. For if science is to progress then people must question and criticise the current state of scientific knowledge.

There is, of course, no virtue in going around falsifying *absurd* hypotheses, such as 'an apple a day makes you good at calculus', or 'people who wear jeans are less likely to have car accidents'. The point is rather to look closely at apparently well-confirmed hypotheses in order to discover their shortcomings.

Take, for example, the scientific law that water boils at 100°C. If you mindlessly boil pan after pan of water, you will never conclusively prove that this law is true and you will not make any meaningful contribution to science. A better strategy would be to look for situations in which water does *not* boil at 100°C. If you adopt this approach, you might discover that, at high altitudes, water boils at less than 100°C. The challenge is then to find an explanation for why water boils at a lower temperature at a higher altitude. And you are then in a position to test new ideas and make real scientific progress.

According to Popper, any theory that resists our best efforts to falsify it should be *provisionally accepted* as the best we have for the time being. But he insists that it cannot be said to be true in any *absolute* sense; for it is always possible that in the future it will be replaced by a better theory. That, after all, is what happened to Newtonian physics!

Criticisms of Popper

Despite the attractions of Popper's philosophy of science, it is itself open to criticism.

Falsification is conclusive in theory but not in practice

Falsificationism turns on the idea that, although confirmation is provisional, falsification is decisive. While this is true in theory, it turns out that in practice falsification is no more conclusive than verification. Imagine, for example, that you do an experiment in the physics laboratory that contradicts one of Newton's laws of motion. Do you announce that you have just disproved Newton? I doubt it! The most reasonable conclusion is that you have messed up the experiment. What this example suggests is that, while in theory a single counter-example is enough to overturn a law of nature, in practice it is not. When there is a conflict between hypothesis and observation we have a choice: we can either reject the hypothesis, or we can reject the observation.

There are in fact many examples in the history of science of scientists refusing to abandon their theories in the face of observational evidence which appeared to contradict them. Here are three such examples.

- ***Physics*** Newton's theory of gravity implied that, given the attractive forces between the stars, the universe should collapse in a gigantic cosmic crunch. Newton saw that this was a serious problem, but rather than abandon his theory, he somewhat desperately concluded that God must be counteracting gravity and keeping the stars in their places.
- ***Chemistry*** When Dimitri Mendeleyev (1834–1907) came up with the periodic table by arranging elements according to their atomic weights, the weights of some elements did not quite fit his model. Mendeleyev did not abandon this theory but concluded that the anomalous weights must be due to experimental error.
- ***Biology*** Charles Darwin's (1809–82) theory of evolution required that the earth be hundreds of millions of years old to allow enough time for species to evolve. But according to the calculations of the leading physicist of the day, Lord Kelvin (1824–1907), the earth was no more than 100 million years old. Kelvin's figure was based on the best knowledge available at the time. Darwin found it 'preposterously inadequate', and he stuck with his theory.

With hindsight, we can say that Newton, Mendeleyev and Darwin were right to stick with their theories in the face of observations that seemed to contradict them. The universe does not collapse in on itself because the speed at which the stars are moving away from each other counteracts gravity. The anomalous weights of some of Mendeleyev's elements were due to the presence of various isotopes. And Kelvin's way of calculating the age of the earth was eventually shown to be wrong.

Auxiliary hypotheses can rescue a falsified theory

What these examples show is that we should not always reject a promising theory as soon as we come across counter-evidence. For the counter-evidence may turn out to be experimental error, or our background assumptions may turn out to be wrong. Of course, if the experimental evidence consistently goes against a theory, then we should eventually abandon it. But a well-established theory may survive a long time in the face of counter-evidence that no one is able to explain away. Consider, for example, the following story told by the philosopher of science Imre Lakatos (1922–74):

> The story is about an imaginary case of planetary misbehaviour. A physicist of the pre-Einsteinian era takes Newton's mechanics and his law of gravitation (*N*), the accepted initial conditions, *I*, and calculates, with their help, the path of a newly discovered small planet, *p*. But the planet deviates from the calculated path. Does our Newtonian physicist consider that the deviation was forbidden by Newton's theory and therefore that, once established, it refutes the theory *N*? No. He suggests that there must have been a hitherto unknown planet *p1* which perturbs the path of *p*. He calculates the mass, orbit, etc. of this hypothetical planet and then asks an experimental astronomer to test his hypothesis. The planet *p1* is so small that even the biggest available telescopes cannot possibly observe it: the experimental astronomer applies for a research grant to build a yet bigger one. In three years' time the new telescope is ready. Were the unknown planet *p1* to be discovered, it would be hailed as a new victory for Newtonian science. But it is not. Does our scientist abandon Newton's theory and his idea of the perturbing planet? No. He suggests that a cloud of cosmic dust

> hides the planet from us. He calculates the location and properties of this cloud and asks for a research grant to send up a satellite to test his calculations. Were the satellite's instruments (possibly new ones, based on a little-tested theory) to record the existence of the conjectural cloud, the result would be hailed as an outstanding victory for Newtonian science. But the cloud is not found. Does our scientist abandon Newton's theory, together with the idea of the perturbing planet and the idea of the cloud which hides it? No. He suggests that there is some magnetic field in that region of the universe which disturbed the instruments of the satellite. A new satellite is sent up. Were the magnetic field to be found, Newtonians would celebrate a sensational victory. But it is not. Is this regarded as a refutation of Newtonian science? No. Either yet another ingenious auxiliary hypothesis is proposed or... the whole story is buried in the dusty volumes of periodicals and the story never mentioned again.

As this story suggests, there is in fact no such thing as a perfect theory, and you will find anomalies and unresolved problems in every area of science. If a theory is well-established and generally successful, then practitioners in the field tend to assume that, with time, outstanding problems will be resolved. For example, when it was discovered that the planet Uranus was not behaving as predicted by Newton's laws, scientists did not abandon Newtonian physics but argued that there must be some unknown planet affecting it. In this case, they rejected neither the observation nor the theory, but made an **auxiliary hypothesis** – the existence of an unknown planet – to explain their observations. This led to the discovery of Neptune in 1846. However, when they tried to explain the misbehaviour of Mercury in the same way by postulating the existence of a planet called Vulcan, they turned out to be wrong. This time Mercury's behaviour could not be explained within the Newtonian paradigm, and this eventually led to a scientific revolution and the replacement of Newtonian physics by the theory of relativity.

The rationalist strand in scientific thinking

When there is a conflict between observation and hypothesis, there are in fact three options:

- reject the hypothesis
- reject the observation
- accept both the hypothesis and the observation and make an auxiliary hypothesis.

What our discussion shows is that there is both a **rationalist** and an **empiricist** strand in scientific thinking. You may remember that a rationalist is someone who sees reason as the main source of knowledge and an empiricist is someone who sees experience as the main source of knowledge. When prediction and observation conflict with one another, a rationalist is more likely to stick with a beautiful theory, and an empiricist is more likely to stick with the observational evidence. Many great scientists have had rationalist sympathies in the sense that they have been unwilling to abandon a promising theory in the light of contrary evidence. Einstein was once asked how he would have reacted if his general theory had not been confirmed by experiment. He replied, 'Then I would have felt sorry for the good Lord. The theory is correct anyway.'

The power of science derives from the fact that it combines reason in the form of mathematics with experience in the form of observational data. The rationalist part of science is the belief that there is order 'out there', and that this order can be

captured in scientific theories. The empiricist part is that if a theory is to survive and flourish then it must be consistent with the observational facts.

What comes out of our discussion of Popper is that scientific theories cannot be conclusively verified or falsified. They cannot be conclusively verified because of the problem of induction; and they cannot be conclusively falsified because, when an observation contradicts a theory, it is always open to you to reject the observation rather than the theory. Strictly speaking then, the concept of *proof* is only relevant to mathematics and logic and we cannot speak of science *proving* things in any absolute sense. In science, as in every other area of knowledge that applies to the world, we have to make do with something less than certainty.

Science and society

We have seen that neither inductivism nor falsificationism can give us an adequate account of the nature of science. A third perspective is provided by the historian and philosopher of science Thomas Kuhn (1922–96) who is best known for having introduced the concept of a **paradigm** to the philosophy of science. As we saw in the appendix to Part 2, a paradigm is an overarching theory shared by a community of scientists, such as physicists, chemists or biologists, which is used to make sense of some aspect of reality. Three important paradigms you are likely to have come across at school are Newtonian mechanics in physics, atomic theory in chemistry, and evolutionary theory in biology.

Normal science

While Popper argued that scientists should constantly be questioning their assumptions, Kuhn drew attention to the fact that during periods of what he calls 'normal science' the vast majority of scientists are busy solving problems within a paradigm while taking the paradigm itself for granted. To take an example mentioned earlier, the irregularity in the orbit of Uranus did not lead scientists to seriously question Newtonian mechanics; rather they tried to solve the problem within the framework of Newtonian mechanics. Popper might condemn such an uncritical approach, but the fact is that, if you are going to get anything done, you cannot endlessly question your assumptions. While great scientists such as Newton, Dalton and Darwin were architects who established new paradigms, most scientists are bricklayers patiently filling in the details and extending the body of scientific knowledge.

Scientific revolutions

Despite his emphasis on the stability of normal science, Kuhn argued that, far from progressing smoothly over time, the history of science is punctuated by revolutions. A **scientific revolution** takes place when scientists become dissatisfied with the prevailing paradigm, and put forward a completely new way of looking at things. If their ideas triumph, the new paradigm will replace the old one and inaugurate another period of normal science. The shift from the geocentric to the heliocentric model of the universe is the classic example of a scientific revolution. Other

examples are the replacement of Aristotelian physics by Newtonian mechanics in the seventeenth century, and the replacement of Newtonian mechanics by Einstein's theory of relativity in the early twentieth century.

While we tend to think of science progressing along the lines of Figure 8.9, according to Kuhn the reality is more like Figure 8.10.

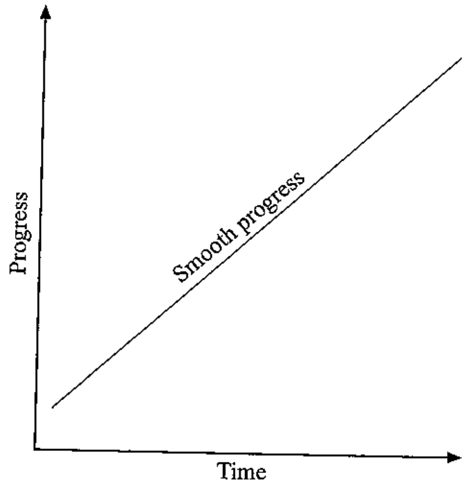


Figure 8.9

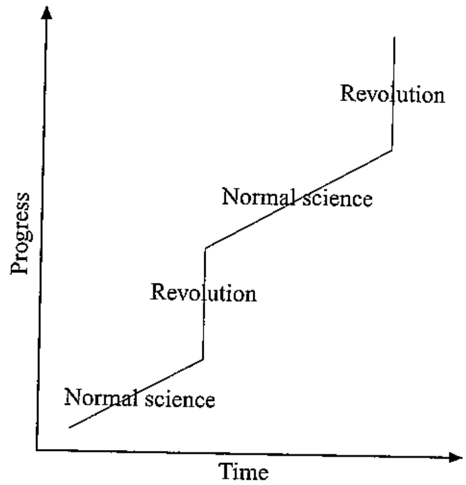


Figure 8.10

> Do you think Figure 8.9 or Figure 8.10 more accurately reflects the way in which a subject with which you are familiar progresses over time?

We said earlier that there is no such thing as a perfect theory in science and that at any given time there are all kinds of problems and puzzles that have not yet been solved. During periods of normal science, there is widespread confidence that such problems can be solved by the existing paradigm. However, if over time the number of unresolved problems reaches a critical mass, some people may begin to question the paradigm itself. If a new paradigm provides a better explanation of things a scientific revolution is likely to occur. But not everyone will be converted to the new way of thinking, and during periods of scientific crisis there are likely to be violent arguments between those who adhere to the old paradigm and those who advocate the new one. Often, the new ideas triumph only after older, more conservative, scientists have died and a new generation has grown up that is familiar with them.

> 1 What truth, if any, do you think there is in the idea that older people are more conservative and suspicious of new ideas than younger people?
>
> 2 Find out how old some of the key figures in the history of science were when they came up with the ideas for which they later became famous. What conclusions, if any, can you draw from your enquiry?

How rational is science?

According to Kuhn, the progress of science is not as rational as is sometimes thought. During periods of scientific crisis there may be no definite point at which we can say it is irrational or unscientific to adhere to an old paradigm rather than convert to a new one. This follows from the point made earlier that in practice a theory can never be conclusively verified or falsified. For we can always dismiss observations that seem to falsify the old paradigm as experimental error or explain them away by making various auxiliary hypotheses. (Recall Lakatos' story of planetary misbehaviour.) Since there may be no purely rational way of choosing between competing theories, Kuhn likened switching from one paradigm to another to a religious conversion which may be influenced by a range of non-scientific factors such as personal ambition and social pressure.

There is doubtless an element of truth in Kuhn's view. We may like to think that scientists are motivated purely by love of truth, but that only tells part of the story. A brief glance at the history of science suggests that other more questionable motives, such as ambition, vanity and envy, also play a role. The vicious **priority disputes** that punctuate the history of science would seem to bear out the wry observation of the French biologist Charles Nicolle (1866–1936) that 'Without ambition and without vanity no one would enter a profession so contrary to our natural appetites.' (A priority dispute is a dispute about who was the first to discover a particular law or come up with a particular theory.) The fact is that scientists are as concerned as the next person with their social status and public recognition. The astronomer Edwin Hubble (1889–1953) was so anxious to get the Nobel Prize that he even employed a public relations expert to help him secure it. Sadly for Hubble, there is no Nobel Prize for astronomy and his efforts were in vain.

The social context also plays a role in the development of science and it may determine a scientist's choice of problems and the questions he or she is willing to investigate. A great deal of scientific research is connected with the military's desire for power and big business's desire for profit, and this has undoubtedly influenced the direction it has taken in recent decades. Ambitious scientists may be attracted to areas in which there is a plentiful supply of money to fund research; and they may shy away from politically sensitive areas, preferring to work in less controversial ones. Moreover, if they seek promotion, they will also be under pressure to conform to the beliefs and values of the scientific community.

Assessment of Kuhn's position

We have now looked at three key elements in Kuhn's theory of science, which can be summarised as follows:

1. During periods of normal science, most scientists do not question the paradigm in which they are operating and focus instead on solving problems.
2. The history of science suggests that, rather than progressing smoothly, science goes through a series of revolutionary jumps.
3. During periods of scientific crisis, there is no purely rational way of deciding between rival paradigms.

To determine how convincing Kuhn's ideas are, let us look more closely at each of the above points.

Normal science

There is probably some truth in Kuhn's claim that during periods of normal science most scientists work within the dominant paradigm without seriously questioning it. The question, however, is whether or not it is a good thing. Admittedly, if scientists are to make any progress they cannot be endlessly questioning their assumptions, but if they *never* do this, their beliefs may end up freezing into dogmatism. That, at least, was Popper's view:

> In my view the 'normal' scientist, as Kuhn describes him, is a person one ought to be sorry for... The 'normal' scientist... has been taught badly. I believe... that all teaching on the University level (and if possible below) should be training and encouragement in critical thinking. The 'normal' scientist, as described by Kuhn,... has been taught in a dogmatic spirit: he is a victim of indoctrination. He has learned a technique which can be applied without asking for the reason why... He is, as Kuhn puts it, content to solve 'puzzles'. The choice of this term seems to indicate that Kuhn wishes to stress that it is not a really fundamental problem which the 'normal' scientist is prepared to tackle: it is rather, a routine problem, a problem of applying what one has learned... The success of the 'normal' scientist consists, entirely, in showing that the ruling theory can be properly and satisfactorily applied in order to reach a solution of the puzzle in question.

? To what extent are you encouraged to question your assumptions in your science classes at school? Can questioning your assumptions sometimes be counter-productive?

Scientific revolutions

We also need to be careful with Kuhn's account of the history of science in terms of revolutions. For it is sometimes taken to imply that *all* of our current scientific beliefs will one day be swept away in a new revolution. However, the fact that science is punctuated by periods of intellectual upheaval does not necessarily mean that when one paradigm replaces another the old one vanishes without trace. In fact, the history of science suggests that scientific knowledge is broadly cumulative and that, over time, scientific knowledge is getting closer to the truth.

Take, for example, physics. Despite the fact that Newtonian mechanics was replaced by Einstein's theory of relativity, the former is still valid across a vast range of phenomena, and is in fact a special case of the latter. This suggests that, rather than being straightforwardly right or wrong, we would do better to think of theories as being more or less inclusive. Despite its limitations, Aristotle's physics provided a reasonable description of many everyday phenomena. It was replaced by Newtonian physics, which is more rigorous and can account for a far wider range of phenomena. But if we wish to explain the motion of electrons inside an atom or the nature of a gravitational field near a black hole then we must turn to the theory of relativity.

We can illustrate the idea of inclusiveness with the following analogy. If you are laying the foundations of a house, you can treat the earth as if it were flat and make your calculations in accordance with plane geometry. However, if you are dealing with a much larger area, then you will need to take into account the curvature of the earth. Here, plane geometry turns out to be a special case of the geometry that is appropriate to the surface of a sphere. In much the same way, physicists see Newtonian mechanics as a useful approximation that can be incorporated into the more general theory of relativity.

Given what we have said, it seems reasonable to suppose that science will continue to progress in a cumulative way in the future. Admittedly, some of our well-tested theories may eventually turn out to be false; but it is difficult to imagine future scientists rejecting our belief that the earth goes round the sun or that water consists of two atoms of hydrogen and one of oxygen. They may, however, discover that such beliefs are approximations to richer and more inclusive theories the details of which we cannot at present imagine.

Choosing between rival paradigms

Kuhn claims that during periods of scientific crisis there is no purely rational way of deciding between rival paradigms, and that a scientist's beliefs will be influenced by the society in which she lives.

As we saw earlier, there is doubtless some truth in this claim. At this point, however, we should distinguish between the *origin* of a belief and its *justification*. For the origin of a belief is not of any great relevance to science. All that matters is that the belief should be *testable*. If it is confirmed by experiment, then we provisionally accept it; if it fails then we reject it.

Since different paradigms interpret the world in fundamentally different ways and we can never conclusively prove which one is true, some have taken Kuhn's ideas to be a form of relativism. However, the fact that there are no conclusive proofs does not mean that scientific knowledge is relative, but simply that – as in every area of knowledge – it depends on *judgement*. We need judgement to decide such things as which factors should be observed and which can be safely ignored, which hypotheses make good sense of the data and which are too outlandish to be useful, which anomalies to take seriously and which to dismiss as experimental error. Such judgements are of course fallible, and they may turn out to be wrong, but this does not make them any less rational. When astronomers speculated that the irregular orbit of Mercury was due to an undiscovered planet, Vulcan, they were wrong; but given the previous successes of Newtonian mechanics, it was a perfectly rational hypothesis. The point, in short, is that just because reason is fallible, it does not follow that it has no value.

One of the great strengths of science is that in the long run it tends to be self-correcting. The fact that scientists work in communities may put pressure on them to conform to the prevailing orthodoxy; but their natural competitiveness will ensure that they check up on one another's results. Moreover, the history of science suggests that good ideas are eventually accepted; and it appears that the time it takes for such ideas to win acceptance is getting shorter. While Copernicus' theory took more than a hundred years to win general acceptance, Einstein's theory was accepted by physicists in less than fifteen years.

Just as good ideas win acceptance, so crackpot theories are weeded out. Despite the support of an oppressive dictatorship, the Soviet biologist Trofim Lysenko (1898–1976), who denounced genetics as 'reactionary and decadent', could not make his wheat grow. Similarly, when in 1989 two scientists, Stanley Pons and Martin Fleischmann, claimed they had produced a nuclear reaction called 'cold fusion' – thereby raising the prospect of a source of energy that would be 'too cheap to meter' – no one else was able to replicate their results and they were quickly discredited.

What comes out of our discussion is that, although there is no straightforward criterion for choosing between rival paradigms, some theories begin to look increasingly plausible and others increasingly implausible as evidence accumulates over time. Beyond a certain point, we are probably justified in dismissing a discredited theory as irrational. Almost no one now takes seriously the claims of the Flat Earth Society. Some ideas have had their day!

Science and truth

We have come a long way in our discussion of scientific knowledge and it is time to take stock. Despite the high regard in which science is held, we have seen that there can be no absolute proof in science and that we can neither conclusively verify nor falsify a hypothesis. But this does not mean that we should embrace relativism. If a scientific theory accounts for the known evidence, is internally consistent, and works in practice, then we should – for the time being at least – accept it as true. Admittedly, it may be replaced by a better theory in the future; but it seems reasonable to think that as one theory follows another we can at least get closer to the truth.

At the same time we should maintain a critical attitude to our scientific beliefs and be willing to question our assumptions. Given our tendency to notice only things that confirm our beliefs, there is, at the psychological level, something to be said for actively seeking evidence that falsifies them. This, I think, is one of the advantages of Popper's approach to science.

A theory of everything?

Some people believe that the ultimate goal of science is to discover a theory that is so general that we have a complete understanding of nature. Yet it seems unlikely that the map of science will ever be able to reproduce the territory of reality. The American physicist Richard Feynman (1918–88) once observed that understanding nature is like understanding chess. In both cases, to understand means to know 'the rules of the game'. Now, to learn the rules of chess is a relatively straightforward matter but, even if you know them all, it is impossible to predict the course of any particular game. (It has been estimated that there are 10^{120} possible moves in chess – an unimaginably large number!) When it comes to nature, we are dealing with a game that is a great deal more complicated than chess. Not only is it very difficult to discover the rules of the scientific game, but – as with chess – even if we succeed in doing this, our understanding remains general rather than specific. You may be armed with all the rules, but you will never get anywhere near knowing all of the ways in which atoms can combine with one another. So a 'complete' understanding of the rules of nature will still leave plenty of room for surprises!

My own hunch is that in the case of nature we will never even know all the rules of the game. Science operates on the assumption that by isolating key variables we can discover the truth. When we do experiments we assume that some factors are relevant and that others can safely be ignored. Up until now this has been a successful strategy. Yet the history of science suggests that as science advances we have to take more and more factors into account that were previously dismissed as irrelevant. Perhaps, as we delve into the complexities of nature, we will eventually find that at the deepest level *everything* is connected to everything else. Since we are finite creatures, we will never be able to grasp the totality of connections, and at that point we will have reached the limits of science.

If you drop a stone into a pond, ripples spread out from the point of impact. The ripples gradually diminish in size, but at what point do the effects of your action end? What has this got to do with the above discussion?

Science and scientism

The success of science and technology has sometimes led people to make extravagant claims about the scope of scientific knowledge. According to the view known as **scientism**, science is the only way we can make sense of reality and discover the truth. A typical representative of this view was the philosopher Rudolf Carnap (1891–1970): 'When we say that scientific knowledge is unlimited, we mean that there is no answer in principle unattainable by science.' What Carnap is, in effect, saying is that science is capable of finding all the answers to all the questions, and if something is non-science then it is little different from nonsense.

There is a big difference between such dogmatic scientism and the more modest conception of science we have looked at in this chapter. We can be proud of what science has achieved; but it is important to keep in mind that it is a fallible human enterprise which may get us closer to the truth but can never give us certainty. Whatever Carnap may have thought, it seems clear that science does not have all the answers, and there are many perplexing questions that lie beyond its scope.

Conclusion

The scientific spirit which is opposed to the uncritical acceptance of dogma has, in large part, been responsible for the enormous growth of knowledge over the last three centuries, and science is widely seen as one of humanity's great success stories. Our pride in science should, however, be tempered by a degree of humility, and it is worth keeping in mind Bertrand Russell's comment that 'Science tells us what we can know, but what we can know is little, and if we forget how much we cannot know we become insensitive to many things of great importance.' It is striking that some of the world's greatest scientists have been aware of the limited nature of their achievements and the extent of their ignorance. Towards the end of his life, Albert Einstein observed that 'All science, measured against reality, is primitive and childlike.' And yet he still believed that it is 'the most precious thing we have'.

Key points

- The success of the natural sciences has led some people to see them as the most important form of knowledge.
- The main difference between science and pseudo-science is that scientific hypotheses can be tested and pseudo-scientific ones cannot.
- According to the traditional picture of the scientific method, science consists of five key steps: observation, hypothesis, experiment, law, theory.
- Among the problems that arise in applying the scientific method are that observation is selective, and that you are more likely to notice things that confirm your hypothesis than those that contradict it.
- Since scientific laws are based on a limited number of observations, we can never be sure that they are true.
- According to Karl Popper, science should be based on the method of conjectures and refutations, and scientists should try to falsify hypotheses rather than verify them.
- In practice, a hypothesis can no more be conclusively falsified than it can be conclusively verified.
- Thomas Kuhn drew attention to the role played by paradigms in science and argued that the history of science is punctuated by revolutionary jumps or 'paradigm shifts'.
- Although scientific beliefs change over time, it could be argued that each new theory is closer to the truth than the previous one.
- Despite the success of the natural sciences, they cannot give us absolute certainty and there are many perplexing questions that lie beyond their scope.

Terms to remember

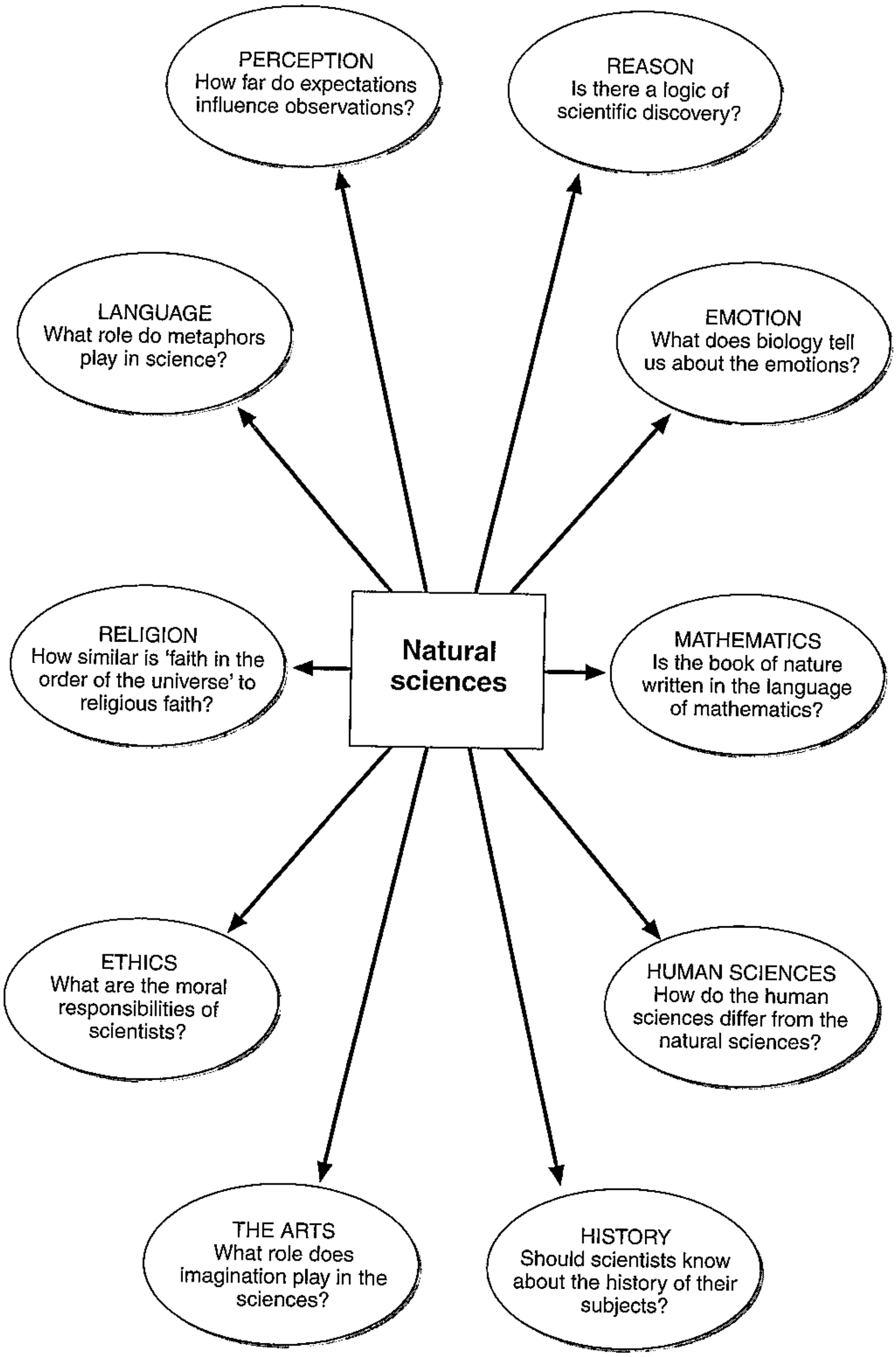
anomaly
conjectures and refutations
controlled experiment
empirical
empiricist
falsification
hypothesis
law
logical positivism
paradigm
physics envy
principle of simplicity
pseudo-science
rationalist
relativism
science worship
scientism

Further reading

A. C. Chalmers, ***What Is This Thing Called Science?*** (Open University Press, 1982). This book gives a good overview of the main ideas about the nature of science. You might not want to read it from cover to cover, but there are useful chapters on traditional inductivism, Popper's falsificationism and Kuhn's paradigms.

Richard P. Feynman, ***'Surely You're Joking Mr. Feynman!'*** (W. W. Norton, 1997), pp. 338–46, 'Cargo Cult Science'. Richard Feynman was one of the great physicists of the twentieth century. In this chapter he considers the difference between science and pseudo-science in his own inimitable and entertaining style.

Linking Questions



Reading Resources

CRYSTALLINE TRUTH AND CRYSTAL BALLS

Richard Dawkins does not pull his punches in this trenchant defence of scientific thinking against the siren voices of pseudo-science.

A celebrated film star 'places four quartz crystal clusters in the four corners of her bathtub every time she takes a bath'. This doubtless has some mystic connection with the following recipe, found on the World Wide Web, for meditation:

'Each of the four quartz crystals in the meditation room should be "programmed" to project gentle, loving, relaxing, crystalline energy towards all those present within the Meditation group. The quartz crystals will then generate a field of positive crystalline energy surrounding everyone in the room.'

Language like this is a con trick. It sounds 'scientific' enough to bamboozle the innocent. 'Programming' is what you do to computers. The word means nothing when applied to crystals. 'Energy' and 'field' are carefully defined notions in physics. There is no such thing as 'loving' or 'crystalline' energy, whether positive or no.

New Age lore advises placing a quartz crystal in your water jug. Another Web site states: *'You will soon appreciate the sparkling purity of your crystal water'*.

See how the trick works? Somebody with no understanding of the real world could make a kind of poetic association with 'crystal clear' water. But that is no more sensible than trying to read by the light of a ('bright as a') button. Or putting ('hard as') nails under your pillow to assist an erection.

'Try the following experiment when you next suffer from flu: hold your personal quartz crystal and visualise yellow light radiating through it, then place your crystal in a jug of water and drink this water the next day; one cup of water at two-hourly intervals. You will be amazed at the result!'

Drinking water at two-hourly intervals is a good idea, anyway, when you have flu. Putting a quartz crystal in it will have no additional effect. In particular, no amount of 'visualising' of coloured light will change the composition of either the crystal or the water.

Pseudoscientific drivel like this is a disturbingly prominent part of the culture of our age. I have limited my examples to crystals because I had to draw a line somewhere. But 'star signs' would have done just as well. Or 'angels', 'channelling', 'telepathy', 'quantum healing', 'homeopathy', 'map dowsing'. There is no obvious limit to human gullibility. We are docile credulity-cows, eager victims of quacks and charlatans who milk us and grow fat. There is a rich living to be made by anyone prepared to prostitute the language – and the wonder – of science.

But isn't it all – crystal ball-gazing, star signs, birth stones, ley-lines and the rest – just a bit of harmless fun? If people want to believe in garbage such as

astrology or crystal healing, why not let them? But it is so sad to think about all that they are missing. There is so much wonder in real science. The universe is mysterious enough to need no help from warlocks, shamans and 'psychic' tricksters. These are, at best, a soul-sapping distraction. At worst, they are dangerous profiteers.

The real world, properly understood in the scientific way, is deeply beautiful and unfailingly interesting. It is worth putting in some honest effort to understand it properly, undistracted by false wonder and prostituted pseudo-science. For illustration, we need look no farther than crystals themselves.

In a crystal like quartz or diamond the atoms are arranged in a precisely repeating pattern. The atoms in a diamond – all identical carbon atoms – are arrayed like soldiers on parade, except that the precision of their dressing far outsmarts the best-drilled guards regiment, and the atomic soldiers outnumber all the people that have ever lived, or ever will. Imagine yourself shrunk to become one of the carbon atoms in the heart of a diamond crystal. You are one of the soldiers in a gigantic parade, but it will seem a little odd because the files are arrayed in three dimensions. Perhaps a prodigious school of fish is a better image.

Each fish in the school is one carbon atom. Think of them moving in space, keeping their distance from each other, and holding precise angles, by means of forces that you can't see, but which scientists fully understand. But if this is a fish school, it is one that, to scale, would fill the Pacific Ocean. In any decent-sized diamond, you are likely to be looking along arrays of atoms numbering hundreds of millions in any one straight line.

Carbon atoms can take up other crystal-lattice formations. To revert to the military analogy, they can adopt alternative drill conventions. Graphite (the lead in pencils) is also carbon, but is obviously nothing like diamond. In graphite, the atoms form sheets of hexagons like chicken wire. Each sheet is loosely bonded to those above and below it, and when impurities are present, the sheets slide easily against each other, which is why graphite is a good lubricant. Diamond is very much not a lubricant. Its legendary hardness abrades the toughest materials. But the atoms in soft graphite and hard diamond are identical; if you could persuade the atoms in graphite crystals to adopt the drill rules of diamond crystals, you would be rich. It can be done, but you need colossal pressures and high temperatures – presumably the conditions that produce diamonds naturally, deep in the earth...

Go into any museum and look at the collection of minerals. Even go into a New Age shop and look at the crystals on display, along with all the other apparatus of mumbo-jumbo and kitsch con trickery. The crystals won't respond to your attempts to 'program' them for meditation, or 'dedicate' them with warm, loving thoughts. They won't cure you of anything, or fill the room with 'inner peace' or 'psychic energy'. But many of them are very beautiful, and it surely adds to the beauty when we understand that the shapes of the crystals, the angles of their facets, the rainbow colours that flash from inside them, all have a precise explanation that lies deep in the patterns of atomic lattice work.

Crystals don't vibrate with mystical, loving energy. But they do, in a much stricter and more interesting sense, vibrate. Some crystals have an electric charge across them which changes when you physically deform the crystal. This 'piezoelectric' effect, discovered in 1880 by the Curie brothers (Marie's husband and his brother), is used in the styluses of record-players (the deforming is done by the groove of the turning record), and in some microphones (the deforming is done by sound waves in the air). The piezo effect works in reverse. When a suitable crystal is placed in an electric field, it deforms itself rhythmically. Often the timing of this oscillation is extremely accurate. It serves as the equivalent of the pendulum or balance wheel in a quartz watch.

Let me tell you one last thing about crystals, and it may be the most fascinating of all. The military metaphor makes us think of each soldier as a yard or two from his neighbours. But actually almost all the interior of a crystal is empty space. My head is 18 centimetres in diameter. To keep to scale, my nearest in the crystalline parade would have to be standing more than a kilometre away. No wonder the tiny particles called neutrinos (even smaller than electrons) pass right through the earth and come out the other side as if it wasn't there (on average, one passes through you every second).

But if solid things are mostly empty space, why don't we see them as empty space? Why does a diamond feel hard and solid instead of crumbly and full of holes? The answer lies in our own evolution. Our sense organs, like all our bits, have been shaped by Darwinian natural selection over countless generations. You might think that our sense organs would be shaped to give us a 'true' picture of the world as it 'really' is. It is safer to assume, however, that they have been shaped to give us a useful picture of the world, to help us to survive. In a way, what sense organs do is assist our brains to construct a useful model of the world, and it is this model that we move around in. It is a kind of 'virtual reality' simulation of the real world. Neutrinos can pass straight through a rock; but we can't. If we try to, we hurt ourselves. When constructing its simulation of rock, the brain therefore represents it as hard and solid. It is almost as though our sense organs are telling us: 'You can't get through objects of this kind'. That is what 'solid' means. That is why we perceive them as 'solid'.

In the same way, we find much of the universe, as science discovers it, difficult to understand. Einstein's relativity, quantum uncertainty, black holes, the Big Bang, the expanding universe, the vast slow movement of geological time – all these are hard to grasp. No wonder science frightens some people. But science can even explain why these things are hard to understand, and why the effort frightens us. We are jumped-up apes and our brains were only designed to understand the mundane details of how to survive the Stone Age African savannah.

These are deep matters, and a short article is not the place to go into them. I shall have succeeded if I have persuaded you that a scientific approach to crystals is more illuminating, more uplifting and also stranger than anything imagined in the wildest dreams of New Age gurus or paranormal preachers. The blunt truth is that the dreams and visions of gurus and preachers are not nearly wild enough. By scientific standards, that is.

THE FALLACY OF SCIENTIFIC OBJECTIVITY

In this article, Hilary Lawson argues that scientific thinking is less objective than is commonly thought and that we don't really understand why it works.

We are ruled by science. It is our religion. Not because of its technological prowess but because it provides the framework of our thinking. Just as, centuries ago, we were ruled by the Church. For, if once we lived in a world of heaven and hell, of the living and the after-life, now we live in a world of atoms and molecules, of planets and galaxies, of laws and forces. Moreover, we think that our account of the world, this scientific account, is true.

But perhaps a time will come when our scientific arguments about subatomic particles or black holes will be seen to be as absurd as theological arguments about the number of angels that can dance on a pin-head: a time when our present theories are regarded as superstitious myths and the institutions of science and the Church are spoken of in the same breath as the means of maintaining orthodox belief. For if the world of the Church was a fiction that in medieval times was regarded as the truth, is not the world of science the fiction that is our truth?

Science appears indisputable because it is based on observation and fact. But observation and facts turn out to be dependent on the theory we choose to believe. We are all familiar with drawings that can be interpreted in two ways.

What we see depends on how we choose to look at it. As a result, it is not possible to imagine that we can in some pure and unhindered way examine reality. We can only do so in the light of a theory or hypothesis. We see the things that we do, the everyday objects that surround us, because of the way we structure the data we receive.

It is because seeing is such an active process that attempts to get computers to see have been so disappointing. It is not sufficient to provide a computer with the data from a television camera, for without a way of dividing this data into groups, the computer is unable to 'see' anything. Seeing is a two-way process. We do not simply see what is there. We have to impose a form on what is there in order to see anything at all. Some of the more successful computer programs work on precisely that basis. In order to 'see', the computer hallucinates its ideal form of an object and searches for something similar in the data it is receiving.

Without the ability to structure what we see, we would be unable to make sense of the world at all. This becomes apparent in cases of visual Agnosia. Until a few years ago, John Collins was in charge of a British subsidiary of an American company, but after an operation he suffered minor brain damage and lost the ability to structure his perception in the way we take for granted. Now John does not recognise himself in the mirror; he does not recognise his wife, his children or grandchildren. Fifty yards from his home he is hopelessly lost; yet he is highly intelligent and can see detail as well as you or I. John is as lost in his world as we might be lost in the depths of a rain-forest. Although we would be able to see the leaves and the branches, we would have no idea what to make of it. And so it is with John, all the time.

As we imagine John's world, we catch sight of what we have to do to give meaning and order to our

experience. Without that order we would be unable to survive. But if seeing relies on our concepts and context, so the facts, observations and theories which make up our currently agreed account of the world – science – depend on context, too.

What we take to be the facts on which scientific theories are based turn out to be products of our own making. Professor David Bohm worked with Einstein in the late Forties and early Fifties and subsequently developed his own account of quantum theory. 'Facts depend on theories, they depend on concepts, they depend on schemata of thought. The very word "fact" comes from a Latin root meaning "to make", as in manufacture; and the fact is what is made or done.' The seeing that is done in science is an active process, more like seeing a picture in a fire, or seeing images in a cloud, than it is like a mirror reflecting nature.

We imagine that the great scientists from Galileo to Einstein proved their results conclusively with the help of repeatable experiments. Historians like Simon Schaffer, however, now argue that scientists did not, and do not, prove their results at all. 'We now all believe the simple fact that the Earth moves round the Sun. And we have a hero – Galileo, who at the start of the 17th century, with a series of very simple experiments, allegedly proved that the Earth does indeed move around the Sun. The Church, who opposed Galileo's views, are treated as if they were charlatans and idiots because they opposed something which seems to us to be absolutely obvious. But in fact the Church had many good arguments on its side and there was no reason for the Church to accept a single word that Galileo was saying.' From the point of view of the Church, truth was not to be found by observing the world (after all, God might have arranged it so as to be deliberately confusing), but by access to the authority of God's own word. Furthermore, even if one were to consider Galileo's work as evidence, there was no reason to believe that what one saw through the telescope was an accurate version of what was actually there. 'None of the evidence which Galileo offered carried conviction, none of it actually proved then that the Earth was moving round the Sun. We believe Galileo's experiments because we believe that the Earth moves round the Sun.'

But if there was no reason to take Galileo seriously, why do we now see the universe as he did? According to Simon Schaffer, it has more to do with practice than with truth. 'By the end of the 17th century, telescopic astronomy had become a very useful resource for the new maritime and commercial powers of northern Europe. Galileo triumphed not because he was right but because his theories were extremely useful. And because they were useful, his observations came to be believed to be true.'

The great heroes of science, from Galileo to Einstein, only made sense of the information available to them by inventing a new order. The same is just as true of all scientists today. Scientific debates are not decided by simply looking at reality, by looking at the facts. The theories and laws of science which we now take for granted are the result of imposing a view on the world. A view that is then backed by the institutions of science.

It appears that science has climbed a grand staircase that leads us from error to truth. But science is full of moments when scientists had chosen one path and discarded another. The paths we did not follow get covered up and forgotten and it seems that there is only one path to truth. It turns out that the path we have taken is the result of a series of accidents. But if science has not discovered the secret key to the truths of the universe, how has it achieved its successes? David Bohm has no straightforward answers: 'Science is a kind of magic that is not recognised to be magical. Fundamentally, we don't understand in any simple terms how it works. If we take physics, for example, we now have a set of equations, both for quantum mechanics and for relativity. But one has no way of picturing just how these mathematical relationships are able to correspond with reality. Theory is a kind of theatre of the mind which gives you insight. This is the major point, to see theory as a creative activity, to see all perception as a creative activity. If you don't have theoretical insight, your facts don't mean anything.'

The gradual recognition of these arguments may affect the practice, the funding and the institutions of science, but its greatest impact is perhaps a personal one. For, if once we believed in the world of the Church, today we believe in the world of science. Our belief in the objectivity of science is now, however, beginning to collapse, although on this occasion there is no alternative world to replace it. Science may remain powerful, but the nature of our belief will have to alter. Science is there to be used – it is not there to tell us how things are. Science is not powerful because it is true: it is true because it is powerful.

The account given here, this story about science, this 'fiction' about science, does not pretend to provide a final picture. It can perhaps try to achieve objectivity but it can't succeed. We can play with the concepts and the categories of our time, but we cannot escape them. To say this is not to say that we can make up any old story, for there are always constraints, but it does mean that we cannot arrive at the final account. For, if once we had faith and then we had science, now we have our necessary fictions.